

Interactive Exercises on Analysis Methods for DC Linear Electrical Circuits

Pedro A. Sousa¹, Manuel G. Gericota¹, Gustavo R. Alves¹

¹ISEP/IPP

Keywords: *interactive exercises, computer-based learning, enhanced learning*

Abstract:

Electrical Engineering students must learn the fundamentals of electricity in a very short time, due to the increasing number and size of areas addressed on EE courses. While some students have been exposed to those fundamentals during secondary level education, others have not. These circumstances increase the complexity of devising a good approach to motivate all students for learning. One example occurs when teaching the analysis methods for DC Linear Electrical Circuits, where the number of all possible arbitrary choices grows exponentially with the number of circuit branches. While first-time-exposed students are required to learn first how to apply the different analysis methods, the remaining students are required to calculate the total number of possible set of equations that solve the circuit. To serve both student groups, we developed an application that helps understanding the way arbitrary choices affect the set of equations generated for solving a customizable circuit.

1 Introduction

Lecturers involved in a 1st-year, 1st-semester discipline, typically enrolled by freshmen, are often faced with a heterogeneous audience, given the different background of each student, in terms of secondary level education. While some have been partially exposed to the core scientific subjects addressed in the course they have just entered (usually in the case of students that had some sort of vocational training) some others are completely blank on those same subjects. Although this situation may vary from country to country, depending on the access system to Higher Education, it is possible to have a general picture of its incidence in Europe, through a careful analysis of the several secondary and higher education types described in [1]. Accepting this situation, the following natural question is on how to motivate the first group while not demoralizing those from the second group. Considering that both groups should be assessed in the same way, i.e. according to the goals proposed for the discipline, the solution may relay on devising exercises with different complexity levels. For instance, on an initial level the student is asked to simple carry out the exercise while on a more advanced level the student is asked to calculate the total number of options within that same exercise.

In the following section we illustrate this principle, applied to a discipline on Fundamentals of Electricity (1st Year, 1st Semester). The subject is analysis methods for DC linear electrical circuits. A Flash[®] [2] application enables students to understand how a set of equations is generated, according to the selected analysis method and to their arbitrary options (level 1), or how many different sets can be generated (level 2), considering all possible arbitrary options.

2 The *Piovere* Flash[®] application

Given a certain electrical circuit, with known elements like resistors and current/voltage sources, a student is generally asked to calculate the variable values, i.e. the current flowing through each resistor (or voltage source) or the voltage across it (or across each current source). In order to calculate those values, the student may apply one of three analysis methods that return a set of equations with a dimension equal to the number of variables. Within each method the student must carry out a number of arbitrary choices that do not affect the final results, which just depend on circuit conditions. Although there are several simulation engines available (in the form of shareware or even freeware) that allow the student to obtain the values of the circuit variables [3], they fail to help understand the way the circuit is analysed. To cover this aspect, we developed a Flash[®] application that helps students understand the way their arbitrary choices affect the set of equations returned by a particular analysis method. The application [4] is available in Portuguese and English, and encompasses the following steps:

1. **Configure circuit** – each of the six branches contains one or zero current / voltage sources, with user selectable polarity, and one or zero resistors. The total number of user options, within this step, is $(5 \cdot 2)^6$, where 5 represents the source combinations, 2 the resistor combinations, and 6 the number of circuit branches. The situation where a branch is configured with no elements, although possible, should be avoided in the current version, as it is not yet fully supported in all analysis methods.

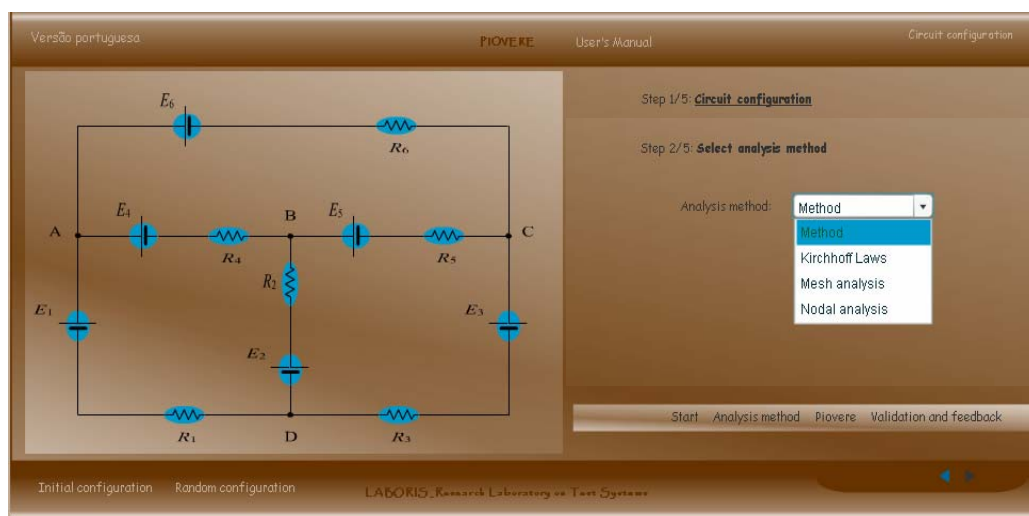


Fig. 1: Selecting the circuit configuration (step 1) and the analysis method (step 2).

2. **Select analysis method** – there are 3 options: simple application of the 1st and 2nd Kirchhoff laws; mesh analysis; and, node analysis.
 - a. **1st and 2nd Kirchhoff laws** – select one redundant node (4 possible options as the circuit contains an equivalent number of nodes), which enables the generation of 3 linear independent equations (i.e. the number of circuit nodes minus one); and, select three independent meshes, including the way each one is traversed (clockwise or anti-clockwise). A set of independent meshes can be derived from a “tree”, i.e. a path that links all nodes. Given a certain “tree” there is only one set of independent meshes if every mesh is created using branches from the “tree” and only one branch from outside the “tree”. For the given circuit, there are 4 nodes (ABCD) all connected to each other, i.e. there is always one path from one node to any other node. This structure allows a total number of $4!/2$ “trees” starting from a given node and ending

on a different node (the $\frac{1}{2}$ factor comes from the fact that, for instance, going from A to D through BC is the same as going from D to A through CB) plus 4 trees that are centred on one node (e.g. the tree centred on node A, which is formed by branches AB, AC, and AD). This number ($4!/2 + 4 = 16$) has to be multiplied by the possible traversal choices for the all set, i.e. 2^3 . So, in total there are $4 \cdot 16 \cdot 8 = 512$ options for this analysis method, within this step.

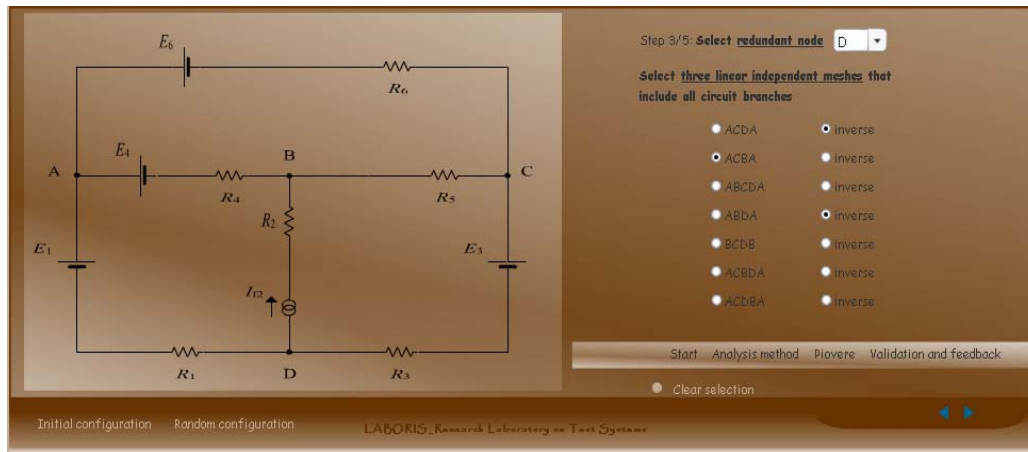


Fig. 2: Selecting a redundant node and a set of three independent meshes (including the way they are traversed: clockwise or anti-clockwise).

- b. **Mesh analysis** – select 3 independent meshes, including the way each one is traversed. Again there are $16 \cdot 2^3 = 128$ possible options (see the previous paragraphs).
 - c. **Node analysis** – select one reference node (again, 4 possible options) and its voltage value (zero by default), which can be any real number.
3. **Define branch currents direction** – there are 2^6 possible choices, where 2 represents the possible directions for each branch current, and 6 the number of circuit branches.
 4. **Generate the set of equations** – from the moment the application returns a set of equations, the user is able to navigate through all previous steps in order to investigate the impact of one (or more) particular option(s).

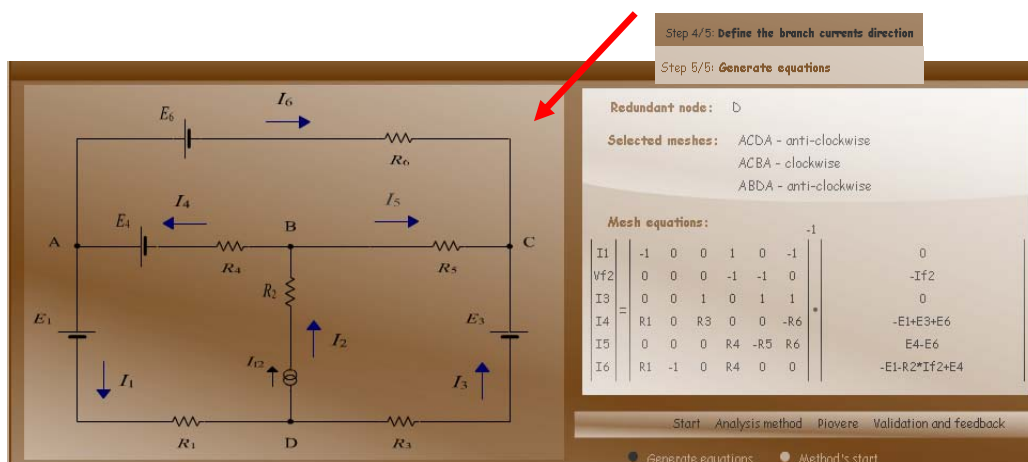


Fig. 3: Defining the branch currents directions (step 3) and generating the set of equations (step 4) according the chosen analysis method and associated options.

Considering just the 1st step, option a) on the 2nd step (i.e. the analysis method identified as “1st and 2nd Kirchhoff laws”), and the 3rd step, there is a total of $10^6 \cdot 4 \cdot 16 \cdot 2^3 \cdot 2^6 \cong 3,2768 \cdot 10^{10}$ possible options. This formula (and the resulting number) is one of the lessons that often students that have learned the analysis methods in secondary school fail to understand. The message we try to pass onto them is that, at Higher Education level, they are required to thoroughly understand the theory (e.g. the analysis methods) and not just how to apply it.

3 Conclusion and future work

We have shown how a simple application targeting the analysis methods for DC linear electrical circuits is able to address two different student groups, enrolled on the same discipline: one group with no previous exposure to those methods, which is required to learn first how to apply them, and another group that must further understand the total number of possible options associated with each method, as part of the same learning goals.

Regarding future work the following directions are still open:

1. Conclude the node analysis method, i.e. accommodate the situation where one branch is simply a short circuit between any two nodes.
2. Validate the all set of generated equations. Given the number of possible options, a feasible methodology to validate the set of equations is to (1) assign values to all circuit elements (1 by default); (2) pass the set of equations to an external tool, such as MATLAB[®] [5], (3) extract the values for the circuit variables; and finally, (4) calculate the circuit power dissipation, which must be zero, i.e. the sum of all power generated within the circuit must be equal to the sum of all power dissipated within the circuit. Repeating this procedure for all possible circuit and analysis methods combinations is one way of validating the set of equations generated by the *Piovere Flash*[®] application.

References:

- [1] Eurodyce, The information network on Education in Europe, available at http://www.eurydice.org/Eurybase/frameset_eurybase.html
- [2] Macromedia Flash[®], available at <http://www.adobe.com>
- [3] Simulators for electrical & electronic circuits, available at <http://www.web-ee.com/Downloads/Simulator/simulation.htm>
- [4] Piovere, available at <http://www.laboris.isep.ipp.pt/piovere>
- [5] MATLAB[®], available at <http://www.mathworks.com/>

Author(s):

Sousa, Pedro, Mr., Gericota, Manuel, Dr. and Alves, Gustavo, Dr.
Polytechnic Institute of Porto, School of Engineering, LABORIS
Rua Dr. Antonio Bernardino de Almeida, 431, Porto - Portugal
{1000173, mgg, gca}@isep.ipp.pt